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ELECTROGONIOMETRIC ANALYSIS OF NORMAL
AND PATHOLOGICAL GAITS

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1. Introduction

In a previous study (3) the high validity, objectivity, and reliability of the electrogoniometer, as well as the use of and kind of information which may be obtained with the instrument, was demonstrated.

This report deals with a study of locomotion in which the electrogoniometer was used exclusively. The report consists of two parts, an analysis of the gait of a normal group of subjects, and an analysis of the pathological gait of a group of patients at a rehabilitation center.

2. Materials and Methods

The knee and ankle electrogoniometers, meters, calibration instruments, and the Model No. 906 Visicorder were used as previously described (3). To determine the instants at which the foot left the ground and the heel touched the ground, flat switches were attached to the toe and the heel. Sometimes a heel elgon was used for this purpose (6).

All walking was done indoors, on the floor or on the treadmill. Whenever the treadmill was used, subjects were first given an opportunity to become used to it before recordings were made.

Cadence was regulated by a metronome. In walking on the floor, the length of step was controlled, when needed, by chalk marks made on the floor.

Subjects. Twenty-eight subjects were used in this study. Thirteen were normal male college students and male inmates of the Hampden County Jail. Seven were normal young women. Eight subjects were patients at the Bay State Rehabilitation Center in Springfield, Massachusetts, who had hemiplegia, multiple sclerosis, cerebral palsy and amputation of the leg above the knee. One patient was recovering from a fractured hip.

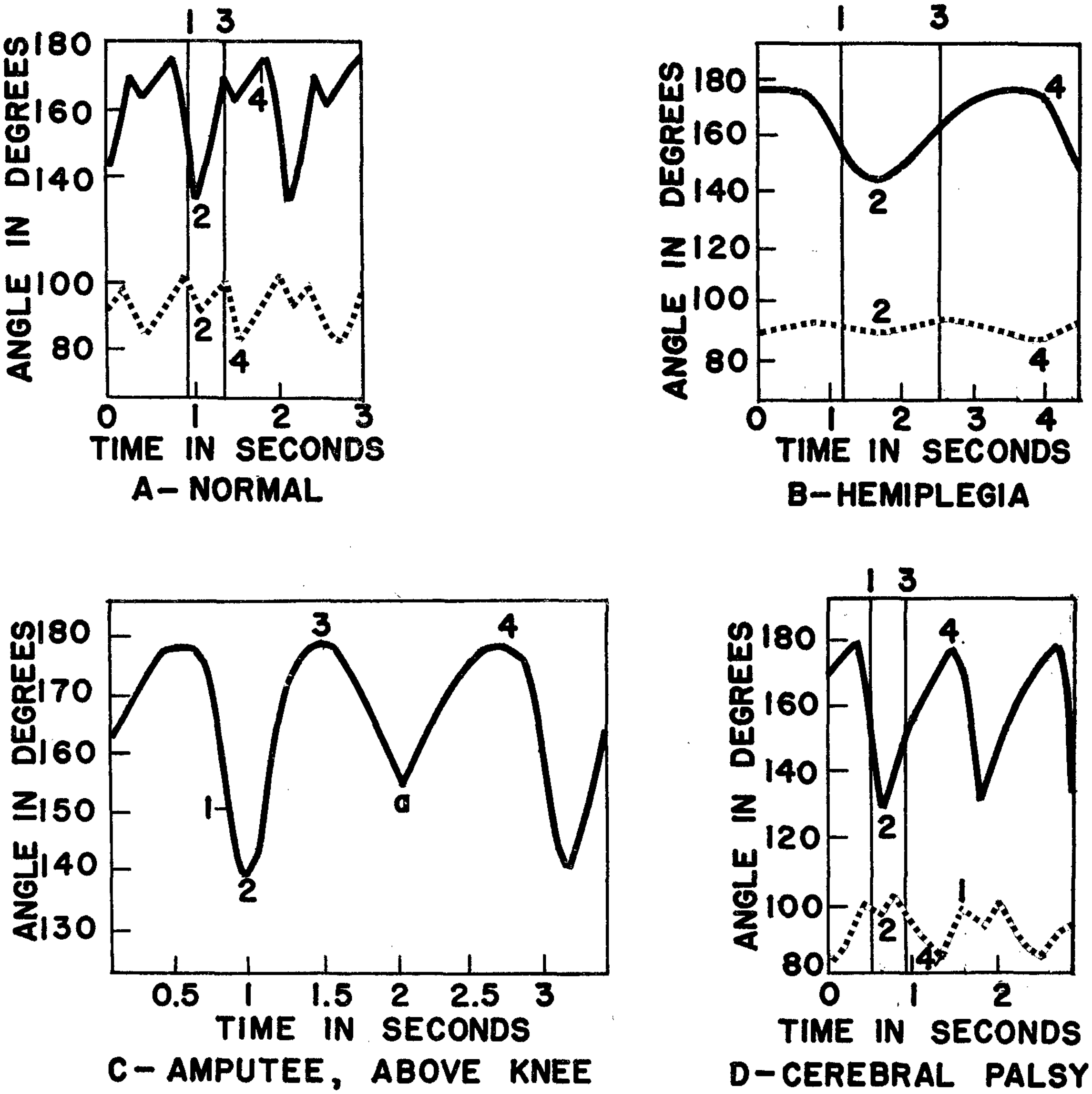

Fig. 1. Normal and Pathological Walking. Solid line, knee action; broken line, ankle action. Reference points: 1, toe leaves the ground; 2, maximum knee and ankle flexion during swing phase; 3, heel contact; 4, maximum knee extension and ankle flexion during support phase; a, knee did not lock up.

PART I

ANALYSIS OF NORMAL GAIT

1. Introduction

Knee and ankle goniograms for walking are shown in Fig. 1. From goniograms obtained, it was possible to determine the following:

a) The ankle angle and the knee angle.

b) The duration of the swing and support phases.

c) The swing-to-support phase ratio.

d) The angular velocity of the knee during the air phase.

e) The effect of increasing the length of step on the above measures.

f) The effect of change in cadence on a, b, c, and d, above.

During walking, there are two definite phases consisting of (1) swing, when the foot is air borne, and (2) support, when the foot is on the ground. In previous reports (3 and 6) the swing phase was referred to as the air phase, and the support phase was called the ground phase.

To analyze the changes in the knee and ankle angles, four reference points were selected. These points were:

The knee joint

1. Toe leaves the ground.
2. Greatest knee flexion during the swing phase.
3. Heel touches the ground (heel contact).
4. Greatest extension during the support phase.

The ankle joint

1. Toe leaves the ground.
2. Greatest ankle flexion during swing phase.
3. Heel touches the ground (heel contact)
4. Greatest ankle flexion during the support phase.

As it may be seen, points 1 and 2 are synchronous for both joints and serve as demarkation points for the swing and support phases. Points 2 and 4 are not synchronous.

One should keep in mind that there may be individual variations in goniograms, and also differences will occur when walking is done on an inclined plane.

2. Results

a. The angle of the knee and ankle during walking. When the toe leaves the ground and the leg is swung forward, there must be a shortening in the length of the limb in order that the foot will not drag on the floor.

This shortening was effected in twenty subjects by an average ankle flexion of eleven degrees and a simultaneous flexion of the knee averaging fifteen degrees. The mean angle for the knee, when the toe left the ground at Point 1, was 139 degrees; and at Point 2, it was 124 degrees. The mean angle for the ankle at the same positions was 107 and 96 degrees, respectively.

When the heel touched the ground (Point 3), the ankle assumed an average position of 101 degrees; and at the same instant, the knee was extended to 173 degrees.

During the support position there was maximum extension in the knee and maximum flexion in the ankle. The mean for the knee was 173 degrees, and for the ankle it was 84 degrees.

Table 1 gives the mean degrees, standard deviation, and standard error of the mean of angles for the knee and ankle for twenty subjects at four reference points.

The range in knee action for normal subjects was from 114 to 179 degrees; and for the ankle, it was from 80 to 118 degrees.

b. <u>Duration of the swing and support phases and swing-to-support time ratio</u>. Table 2 gives the duration of the swing and support phases and the ratio of swing time to support time during natural walking.

$$\text{Swing-to-support time ratio} = \frac{\text{swing time}}{\text{support time}}$$

The mean swing phase time was .4 of a second; and the mean support phase time was .7 of a second. The mean swing-to-support time ratio was .52.

The swing phase time ranged from .3 to .5 of a second, and support phase time range was .5 to .9 of a second. The swing-to-support time ratios ranged from .38 to .83.

c. <u>The effect of lengthening the step on the angles formed by the knee and ankle when cadence was controlled</u>. The effect of lengthening the step on the knee angle may be seen in Table 3, and the effect on the ankle is shown in Table 4. The long step was twelve inches longer than the short one.

<u>The knee angle</u>. The mean knee angle at Point 2 during normal steps was 120 degrees. When steps were lengthened, the angle became 112 degrees. This difference was found to be statistically significant at the .01 level of confidence.

At Point 4 the mean angle was 175 degrees during usual steps; and when steps were lengthened, the angle became smaller by 4 degrees. This difference was statistically significant at the .05 level of confidence.

No statistically significant differences were found at Point 1 (toe left the ground) or when the heel touched the ground (Point 3).

<u>The ankle angle</u>. The angle formed by the ankle when the toe left the ground (Point 1) for normal length steps was 100 degrees; when

steps were lengthened by twelve inches, the ankle increased by 5 degrees. This difference was statistically significant at the .05 level of confidence.

The angle formed at Point 4 for normal length steps was 86 degrees; when steps were lengthened, the angle decreased by 10 degrees. This difference was statistically significant between .05 and .01 levels.

Differences for angles at Point 2 and Point 3 were not statistically significant.

d. The effect of cadence on the angle formed by the knee and by the ankle when length of step was controlled. Table 5 shows the angle of the knee, and Table 6 shows the angle of the ankle when subjects walked at slow, medium and fast cadences. Slow cadence was 100 steps per minute; medium was 120 steps per minute; and fast was 140 steps per minute.

Statistically significant differences were found in degrees of the knee angle at the following points: 2 (swing phase) between slow and medium cadence; and 3 (heel contact) between slow and fast cadence, and between medium and fast cadence. Of the twelve comparisons made, only these three differences were found to be significant changes.

Statistically significant differences were found in the angle formed by the ankle at Point 4 between the slow and medium, and between the slow and fast.

e. The effect of cadence on the duration of the swing and support phases and the swing-to-support phase ratio when length of step was uncontrolled. Table 7 contains results of the effect of cadence on the time the foot was air borne, on the time it was on the ground, and on the swing-to-support time ratio when length of step was controlled.

When cadence was increased, the time for both swing and support phases became shorter. The mean swing time for slow cadence was 410 milliseconds; for medium cadence, it was 340 milliseconds; and for fast cadence, it was 300 milliseconds. The support time was 670 milliseconds for slow cadence, 550 milliseconds for medium, and 480 milliseconds for fast cadence.

The swing-to-support ratio increased with increases in cadence. These ratios were .61, .63, and .64 for slow, medium, and fast cadence, respectively.

f. Angular velocity of the knee during the swing phase in walking. Angular velocity of the knee during the swing phase when subjects walked naturally may be seen in Table 8.

During flexion the knee moved an average of 13 degrees. Mean time needed for this movement was 60 milliseconds, and mean angular velocity was 228 degrees per second.

In extension the average amplitude was 49 degrees, and the time required for the movement was 310 milliseconds. Mean angular velocity was 161 degrees per second.

Angular velocity during flexion ranged from 160 to 360 degrees per second; during extension, the range was 130 to 192 degrees per second.

g. The effect of cadence on angular velocity of the knee when length of step remained constant. Table 9 shows angular velocity of the knee during flexion in the swing phase when subjects walked at slow, medium, and fast cadence, and the step length remained constant. Table 10 shows results obtained during extension. An increase in the angular velocity may be observed in both flexion and extension movements with increase in cadence.

During flexion, the angular velocity of the knee at slow cadence was 183 degrees per second; at medium cadence, it was 209 degrees per second; and at fast cadence, it was 214 degrees per second.

During extension, mean angular velocity was 179 degrees per second at slow cadence, 184 degrees per second at medium cadence, and 199 degrees per second at fast cadence.

h. The effect of cadence on angular velocity of the knee when length of step was not controlled. Table 11 shows angular velocity of the knee during flexion in the swing phase when subjects walked at slow, medium, and fast cadence and when length of step was not controlled. Table 12 shows the results for extension. Angular velocity for both flexion and extension increased from slow to medium cadence, but decreased from medium to fast cadence during flexion. Probably the length of the step was increased.

During flexion, mean angular velocity of the knee at slow cadence was 126 degrees per second; at medium cadence, it was 160 degrees per second; at fast cadence, it was 109 degrees per second.

During extension, mean angular velocity was 198 degrees per second at slow cadence, 192 degrees per second at medium cadence, and 191 degrees per second at fast cadence.

i. The effect of lengthening the step on angular velocity of the knee when cadence remained constant. The first half of Table 13 shows the effect of lengthening the step on angular velocity of the knee during flexion in the swing phase, and the second half of the same table shows the results for extension. During flexion, angular velocity increased when steps were lengthened.

Mean angular velocity of the knee for normal steps was 90 degrees per second. When steps were lengthened by twelve inches, the mean angular velocity was 161 degrees per second.

During extension, mean angular velocity of the knee for normal steps was 180 degrees per second; when steps were lengthened, it was 182 degrees per second.

3. Discussion

As it had been expected, the duration of swing phase and support phase, and the swing-to-support ratio for the subjects in this study showed a wide variability when cadence was not controlled. When cadence was controlled, the range in these measures was narrowed.

According to Drillis (2) a swing-to-support ratio range of .5 to .8 is normal. In all situations where cadence was controlled, the subjects used in this study were within this range, except one subject whose ratio at first cadence was .88. The reduction in support time was greater than the reduction in swing time when cadence was increased.

It was to be expected that cadence would have an effect on the ankle angle and the knee angle. It is known that when cadence is increased the level of the hips above the ground becomes lower (5). Therefore, the knee must be flexed more as the foot is swung forward, and the ankle is expected to flex more at Point 4. Also as the body develops greater velocity with the increased cadence, there is need for greater restraint when the heel is placed on the ground. The restraint or shock absorbing is achieved through a greater knee flexion at this point. Experimental findings substantiated this expectation.

When cadence was increased and step length was controlled, angular velocity of the knee increased during flexion. Also, with cadence remaining constant, angular velocity of the knee was greater when steps were lengthened and vice versa. Therefore, it is believed that when length of step was not controlled, the increase in angular velocity of the knee from slow to medium cadence meant that steps were lengthened; and during decrease from medium to fast, the steps were shortened.

It should be noted that none of the subjects in this part of the study touched the heel to the ground with the knee in full extension. One need only to observe an amputee walking with an artificial leg that does reach full extension to become aware of how this action is peculiarly abnormal.

However, the view that the knee is at full extension at the time the heel touches the ground was held by Marks (4) who utilized stroboscopic photography. In the same investigation Marks also states that the shock of the heel touching the ground is absorbed by seven degrees of flexion (4).

Goniograms obtained in this study reveal that the so called "shock absorbing" action was sometimes absent when subjects walked at slow cadence, but increased with faster cadence and long steps. In one subject, flexion, after the heel touched the ground while taking long steps, increased to an average of 22 degrees.

PART II

ANALYSIS OF PATHOLOGICAL GAIT

Analysis was made of the gait of eight patients at the Bay State Rehabilitation Center in Springfield, Massachusetts. Walking was done on the floor. Two patients were above-the-knee amputees, two had multiple sclerosis, two had cerebral palsy, one had a hemiplegia as the result of a cerebrovascular accident, and one was recovering from a fractured hip.

1. Results

a. The angle of the knee and of the ankle. Table 14 shows the angles of the knee and ankle at four reference points for each of the patients used in this part of the study. Goniograms of pathological gait may be seen in Fig. 1.

A comparison of the pathological and normal goniograms shows that the knee curves of the hemiplegic and of the palsied patients did not have two "humps" present in the normal curve. Although the amputee had two humps, the cause of depression a, in the middle, was not the result of a shock absorbing action. When the heel touched the ground, for some reason the prosthesis in both patients did not lock and there was considerable knee flexion (as much as 25 degrees) during the ground phase. (See Fig. 1, C.) If it were not for the canes they used, these subjects would have fallen at that point.

The ankle curve of the palsied patient resembled that of the normal subject, but in the hemiplegic patient the pattern was different. Instead of periodic double peaked elevations, there was a rather shallow undulation.

In the multiple sclerosis patients (goniograms not given), the knee curve followed the normal pattern, but the ankle curve was more shallow than most normal curves.

The knee angle when the toe left the ground ranged from 130 to 168 degrees; at Point 2 the range was 116 to 148 degrees; at the heel contact the knee angle ranged from 158 to 180 degrees; and at Point 4 the range was from 176 to 180 degrees.

The angle formed by the ankle when the toe left the ground ranged from 88 to 108 degrees; at Point 2 the range was 88 to 104 degrees. When the heel touched the ground, the range was 88 to 110 degrees. At Point 4 the range was 82 to 91 degrees.

b. Duration of the swing and support phases and the swing-to-support phase ratio. It may be seen in Table 15 that the swing phase ranged from 300 to 900 milliseconds. In five of the patients (hemiplegia, multiple sclerosis, fractured hip, and two cerebral palsy) swing time exceeded 400 milliseconds. Support phase ranged from .9 to 2.1 seconds. Support time for six patients exceeded 900 milliseconds.

The range for swing-to-support ratio was .19 to .63. Five of the ratios were .38 or smaller.

c. Angular velocity of the knee. Angular velocity of the knee during the swing phase may be seen in Table 16. The amplitude of the knee during downswing flexion ranged from 22 to 60 degrees. Time needed for this movement ranged from 200 milliseconds to 1.0 second, and angular velocity ranged from 50 to 125 degrees per second.

During upswing extension, the amplitude of knee movement ranged from 6 to 28 degrees, and the time ranged from 200 milliseconds to 1.0 second, and the range in angular velocity was 22 to 200 degrees per second.

2. <u>Discussion</u>

Except for three patients (an amputee, one with multiple sclerosis and one with cerebral palsy) it would appear that gait as executed by this group was done in a rather stiff-legged pattern. There was a smaller degree of flexion than in normal subjects. The range in knee motion for normal subjects was 49 degrees. For the three patients indicated, the mean range of motion was 37 degrees.

The range of ankle action was also diminished in all patients. While in normal subjects the difference between angles at Points 1 and 2 was about 11 degrees, in patients it ranged from 0 to 4 degrees. The absence of ankle flexion is a limiting factor when knee flexion in the swing phase is reduced. Patients with such limitation would have difficulty walking on other than flat surfaces as the toe would drag on the ground.

One of the cerebral palsied patients had a toe drop which was probably compensated for by knee flexion to 116 degrees during the swing phase. The compensating action would also appear to be true for one of the multiple sclerosis patients whose knee angle was 121 degrees during the swing phase. The other multiple sclerosis patient had no compensatory knee flexion, and his ambulation was slower and more laborious than the first one.

Swing-to-support phase time quite obviously deviated from normal, and this is particularly reflected in the swing-to-support ratios of .16 and .19 for the two amputee patients, as compared with a mean of .52 for normal. The lowest ratio for normal subjects was .38.

Likewise, rather apparent deviations in angular velocity of the knee were represented in all patients except one amputee when velocities for both flexion and extension were considered. The velocities for the patients were considerably slower than normal subjects.

Of the entire group, patient number one, who had hemiplegia, had the gait of most limitation. This is seen in the small range of motion in both ankle and knee action; swing and support times which were the longest recorded, and angular velocity of the knee was a mere 55 degrees per second during flexion and extension.

3. <u>Summary and Conclusions</u>

The purpose of this study was to analyze normal and pathological gaits by use of electrogoniometry. The analysis included the action of the ankle and knee joints, the duration of the swing and support phases, the swing-to-support time ratio, and angular velocity at the knee. Twenty-six subjects with normal gait and eight subjects with abnormal gait were used.

The effect of changes in cadence and step length upon the ankle and knee action was investigated. The findings of significance were:

1. Longer steps caused greater knee flexion.
2. Longer steps caused greater ankle extension when the toe left the ground (Point 1).
3. Longer steps increased ankle flexion at Point 4.
4. Increased cadence caused greater knee flexion at the heel contact (Point 3).
5. Increased cadence caused greater ankle extension during the support phase.

It was further observed that increased cadence caused a greater decrease in support time than in swing time.

Angular velocity at the knee, when step length was not controlled, became greater when cadence was increased from 100 to 200 steps per minute. But when cadence increased to 140 steps per minute, angular velocity at the knee became less.

It may be concluded from the results of this study that electrogoniometry is a practical, relatively simple and fast means of measuring and analyzing various factors of human locomotion.

We want to express our thanks to Dr. James Fisher, Mr. Robert Van Wart and Mrs. Constance Wickman, of the Bay State Rehabilitation Center, for their co-operation in testing the patients.

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TABLE 1. THE DEGREES OF THE KNEE AND THE ANKLE ANGLES DURING WALKING

	Reference Points 1		2		3		4	
	*Toe Leaves The Ground		Swing Phase, Greatest Flexion		Heel Contact		Support Phase Greatest Extension Flexion	
	Knee	Ankle	Knee	Ankle	Knee	Ankle	Knee	Ankle
Mean	138.6	106.90	123.95	95.85	172.50	101.05	173.4	83.65
S.D.	6.71	5.85	7.79	3.86	4.06	3.53	3.64	1.75
S.E.M.	1.54	1.34	1.79	.89	.93	.81	.84	.40

*Also referred to as "toe break."

TABLE 2. DURATION OF SWING AND SUPPORT PHASES AND SWING-TO-SUPPORT PHASE RATIO DURING WALKING

	Swing Phase In Seconds	Support Phase In Seconds	Swing-to-Support Ratio
Mean	.355	.695	.52
S.D.	.059	.112	.117
S.E.M.	.014	.026	.027

TABLE 3. THE EFFECT OF STEP LENGTH ON THE DEGREES OF ANGLE OF THE KNEE WHEN CADENCE WAS CONTROLLED

	Reference Points							
	1		2		3		4	
	Toe Leaves The Ground		Swing Phase Greatest Flexion		Heel Contact		Support Phase Greatest Extension	
	*Short	Long	Short	Long	Short	Long	Short	Long
Mean	128.9	126.3	120.3	112.0	173.0	166.7	175.4	171.4
S.D.	7.16	7.21	5.60	5.35	6.35	8.86	4.50	2.77
S.E.M.	2.92	2.94	2.29	2.18	2.59	3.62	1.84	1.13

*Short steps were of a normal length for the individual, and long steps were 12 inches longer.

The means at reference point 2 are significantly different at the .01 level.

The means at reference point 4 are significantly different at the .05 level.

TABLE 4. THE EFFECT OF STEP LENGTH ON THE DEGREES OF THE ANGLE OF THE ANKLE WHEN CADENCE WAS CONTROLLED

	Reference Points							
	1		2		3		4	
	Toe Leaves The Ground		Swing Phase Greatest Flexion		Heel Contact		Support Phase Greatest Flexion	
	*Short	Long	Short	Long	Short	Long	Short	Long
Mean	99.6	105.4	94.6	98.6	99.4	102.0	84.3	78.9
S.D.	2.61	6.21	3.50	9.30	3.66	6.68	2.49	5.00
S.E.M.	1.07	2.54	1.43	3.80	1.49	2.73	1.02	2.04

*Short steps were of a normal length for the individual, and long steps were 12 inches longer.

The means at reference point 1 are significantly different at the .05 level.

The means at reference point 4 are significantly different between the .05 and .01 levels.

TABLE 5. THE EFFECT OF CHANGE IN CADENCE ON THE DEGREES OF ANGLE OF THE KNEE WHEN LENGTH OF STEP WAS CONTROLLED

	Reference Points											
	1			2			3			4		
	Toe Leaves The Ground			Swing Phase Greatest Flexion			Heel Contact			Support Phase Greatest Extension		
	Slow	Medium	Fast	Slow	Medium	Fast	Slow	Medium	Fast	Slow	Medium	Fast
Mean	127.1	127.1	124.0	114.3	116.3	115.4	172.0	169.7	166.8	173.7	174.3	172.6
S.D.	10.08	6.66	9.50	8.02	7.04	7.46	4.14	5.70	6.83	2.49	2.27	2.97
S.E.M.	4.13	2.72	3.88	3.27	2.87	3.05	1.69	2.33	2.79	1.02	.93	1.21

Slow cadence: 100 steps per minute; medium cadence: 120 steps per minute; fast cadence: 140 steps per minute.

The means at reference point 2, for slow and medium cadence, are significantly different at the .05 level.

The means at reference point 3 are significantly different for slow and medium cadence between the .05 and the .01 levels and significantly different for slow and fast cadence at the .05 level.

TABLE 6. THE EFFECT OF CHANGE IN CADENCE ON THE DEGREES OF ANGLE OF THE ANKLE WHEN LENGTH OF STEP WAS CONTROLLED

	Reference Points											
	1			2			3			4		
	Toe Leaves The Ground			Swing Phase Greatest Flexion			Heel Contact			Support Phase Greatest Flexion		
	Slow	Medium	Fast	Slow	Medium	Fast	Slow	Medium	Fast	Slow	Medium	Fast
Mean	100	98.3	100.8	92.3	92.5	93.4	97.6	100.3	99.4	81.3	82.7	83.7
S.D.	6.05	4.46	6.56	3.92	2.77	3.33	3.74	7.44	7.38	2.19	1.58	.70
S.E.M.	2.47	1.82	2.68	1.60	1.13	1.36	1.55	3.04	3.01	.89	.65	.29

Slow cadence: 100 steps per minute; medium cadence: 120 steps per minute; fast cadence: 140 steps per minute.

The means at reference point 4, for slow and medium cadence, are significantly different at the .05 level, and for slow and fast cadence are significantly different between the .05 and the .01 levels.

TABLE 7. THE EFFECT OF CADENCE ON THE DURATION OF SWING AND SUPPORT PHASES, SWING-TO-SUPPORT PHASE RATIO, WHEN LENGTH OF STEP WAS CONTROLLED

	Duration of Swing Phase in Milliseconds			Duration of Support Phase in Milliseconds			Swing-to-Support Ratio		
	Slow	Medium	Fast	Slow	Medium	Fast	Slow	Medium	Fast
Mean	405	343	300	669	554	476	.611	.634	.641
S.D.	44	25	30	43	79	43	.103	.108	.125
S.E.M.	18	10	12	18	32	18	.042	.044	.051

Slow cadence: 100 steps per minute; medium cadence: 120 steps per minute; fast cadence: 140 steps per minute.

TABLE 8. AMPLITUDE, DURATION AND ANGULAR VELOCITY OF THE KNEE ACTION DURING SWING PHASE

	Flexion Downswing From Point 1 to Point 2			Extension Upswing From Point 2 to Point 3		
Subject	Amplitude of Motion in Degrees	Time in Milli-seconds	Velocity in Degrees Per Second	Amplitude of Motion in Degrees	Time in Milli-seconds	Velocity in Degrees Per Second
1	16	75	213	52	300	173.3
2	18	50	360	53	300	176.7
3	12	50	240	49	375	130.7
4	9	50	180	58	375	154.7
5	18	75	240	48	250	192.0
6	10	50	200	44	275	160.0
7	12	75	160	42	300	140.0
Mean	13.57	61	227.57	49.43	311	161.06
S.D.	3.46	12.37	60.53	5.05	44.06	19.83
S.E.M.	1.41	5.04	24.70	2.06	17.99	8.10

TABLE 9. THE EFFECT OF CADENCE ON ANGULAR VELOCITY OF THE KNEE DURING DOWNSWING (BETWEEN POINTS 1 and 2) WHEN STEP LENGTH WAS CONTROLLED

	Amplitude of Motion in Degrees			Time in Milli-seconds			Velocity in Degrees Per Second		
	Slow	Medium	Fast	Slow	Medium	Fast	Slow	Medium	Fast
Mean	14.00	10.90	9.70	81	53	44	182.40	208.60	213.60
S.D.	6.23	3.52	4.71	22	11	27	89.89	54.89	133.30
S.E.M.	2.55	1.44	1.92	9	5	11	36.70	22.41	54.43

Slow cadence: 100 steps per minute; medium cadence: 120 steps per minute; fast cadence: 140 steps per minute

TABLE 10. THE EFFECT OF CADENCE ON ANGULAR VELOCITY OF THE KNEE DURING UPSWING (BETWEEN POINTS 2 AND 3) WHEN STEP LENGTH WAS CONTROLLED

	Amplitude of Motion in Degrees			Time in Milli-seconds			Velocity in Degrees Per Second		
	Slow	Medium	Fast	Slow	Medium	Fast	Slow	Medium	Fast
Mean	57.40	53.40	51.40	325	292	259	179.10	184.00	199.00
S.D.	10.46	9.90	10.78	28	18	16	42.94	39.00	42.96
S.E.M.	4.29	4.04	4.40	11	7	7	17.53	15.92	17.54

Slow cadence: 100 steps per minute; medium cadence: 120 steps per minute; fast cadence: 140 steps per minute.

TABLE 11. THE EFFECT OF CADENCE ON ANGULAR VELOCITY OF THE KNEE DURING DOWNSWING (BETWEEN POINTS 1 and 2) WHEN STEP LENGTH WAS NOT CONTROLLED

	Amplitude of Motion in Degrees			Time in Milliseconds			Velocity in Degrees Per Second		
Subject	Slow	Medium	Fast	Slow	Medium	Fast	Slow	Medium	Fast
1	15	7	4	100	80	75	150	87.5	50.0
2	13	6	8	100	50	75	130	120.0	100.0
3	12	12	12	75	50	75	150	240.0	150.0
4	12	15	15	100	100	60	120	150.0	250.0
5	13	17	12	100	50	100	130	340.0	120.0
6	8	8	2	50	75	75	160	100.0	25.0
7	4	4	2	100	50	28	40	80.0	66.7
Mean	11	9.9	7.9	89	65	70	125.7	159.6	108.8
S.E.	3.46	4.52	4.91	18	19	20	37.36	89.25	69.79
S.E.M.	1.41	1.84	2.00	7	8	8	15.26	36.44	28.50

Slow cadence: 100 steps per minute; medium cadence: 120 steps per minute; fast cadence: 140 steps per minute.

TABLE 12. THE EFFECT OF CADENCE ON ANGULAR VELOCITY OF THE KNEE DURING UPSWING (BETWEEN POINTS 2 AND 3) WHEN STEP LENGTH WAS NOT CONTROLLED

	Amplitude of Motion in Degrees			Time in Milliseconds			Velocity in Degrees Per Second		
	Slow	Medium	Fast	Slow	Medium	Fast	Slow	Medium	Fast
Mean	52.10	50.00	44.10	269	264	230	198.30	191.90	191.30
S.D.	4.42	8.99	4.91	40	40	25	37.54	46.09	27.27
S.E.M.	1.80	3.67	2.00	16	16	10	15.37	18.82	11.14

Slow cadence: 100 steps per minute; medium cadence: 120 steps per minute; fast cadence: 140 steps per minute.

TABLE 13. THE EFFECT OF STEP LENGTH ON ANGULAR VELOCITY OF THE KNEE WHEN CADENCE WAS CONTROLLED

	Downswing						Upswing					
	From Point 1 to Point 2						From Point 2 to Point 3					
	Amplitude of Motion in Degrees		Time in Milli-seconds		Velocity in Degrees Per Second		Amplitude of Motion in Degrees		Time in Milli-seconds		Velocity in Degrees Per Second	
	*Short	Long	Short	Long	Short	Long	Short	Long	Short	Long	Short	Long
Mean	8.9	14.3	107	92	90.0	160.7	57.0	56.1	317	309	180.0	181.5
S.D.	3.16	3.61	22	25	48.07	41.65	13.63	10.81	44	32	47.30	29.49
S.E.M.	1.29	1.47	9	10	19.63	17.01	5.56	4.41	18	13	19.31	12.04

*Short steps were of a normal length for the individual, and long steps were 12 inches longer.

TABLE 14. THE DEGREES OF ANGLE OF THE KNEE AND ANKLE IN PATHOLOGICAL GAIT

	Reference Points 1		2		3		4	
	Toe Leaves The Ground		Swing Phase Greatest Flexion		Heel Contact		Support Phase Greatest Extension	
Condition	Knee	Ankle	Knee	Ankle	Knee	Ankle	Knee	Ankle
Left Hemiplegia	168	88	140	88	162	88	178	84
Above-The-Knee Amputee	144		138		180		180	
Above-The-Knee Amputee	163		148		178		180	
Multiple Sclerosis	158	108	142	104	178	110	178	90
Multiple Sclerosis	130	97	121	98	163	102	177	84
Fractured Hip	151	100	139	98	174	100	180	91
Cerebral Palsy	150	100	134	96	158	100	176	82
Cerebral Palsy	130	104	116	104	176	92	176	84

TABLE 15. DURATION OF THE SWING AND SUPPORT PHASES AND THE SWING-TO-SUPPORT RATIO IN PATHOLOGICAL GAIT

Condition	Duration (in seconds): Swing Phase	Support Phase	Swing-to-Support Ratio
Left Hemiplegia	.9	2.4	.38
Above-The-Knee Amputee	.3	1.8	.16
Above-The-Knee Amputee	.4	2.1	.19
Multiple Sclerosis	.8	1.6	.50
Multiple Sclerosis	.4	1.2	.33
Fractured Hip	.6	1.6	.38
Cerebral Palsy	.5	.8	.63
Cerebral Palsy	.5	.9	.56

TABLE 16. ANGULAR VELOCITY OF THE KNEE IN PATHOLOGICAL GAIT DURING SWING PHASE

Condition	Downswing Amplitude of Motion in Degrees	Downswing Time in Milli-seconds	Downswing Velocity in Degrees Per Sec.	Upswing Amplitude of Motion in Degrees	Upswing Time in Milli-seconds	Upswing Velocity in Degrees Per Sec.
Left Hemiplegia	28	500	56	22		22
Above-The-Knee Amputee	6	90	67	42	210	200
Above-The-Knee Amputee	15	120	125	30	280	107
Multiple Sclerosis	16	320	50	36	480	75
Multiple Sclerosis	9	125	72	42	400	105
Fractured Hip	12	200	60	35	400	88
Cerebral Palsy	16	200	80	24	400	60
Cerebral Palsy	14	120	117	60	380	158